Signal averaged P wave compared with standard electrocardiography or echocardiography for prediction of atrial fibrillation after coronary bypass grafting

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Abstract
Objective—**To define the clinical value of the signal averaged P wave (SAPW) and to compare it with the standard electrocardiogram (ECG), echocardiogram, and clinical assessment for the prediction of atrial fibrillation after coronary bypass grafting (CABG).**
Design—**Prospective validation cohort study.**
Setting—**Regional cardiothoracic centre.**
Patients—**201 unselected patients undergoing first elective CABG were recruited over six months. Patients requiring concomitant valve surgery were excluded.**
Main outcome measures—**Age, sex, cardiothoracic ratio, and cardioactive drugs were noted. P wave specific SAPW recordings, ECG, and M mode echocardiograms from which left atrial diameter was measured were performed within 24 hours of surgery. Filtered P wave duration (SAPWD), spatial velocity, and energy were calculated from the SAPW. From the ECG, lead II P wave duration, P terminal force in lead V1, total P wave duration, and isoelectric interval were measured. Patients had Holter monitoring for 48 hours postoperatively and daily ECGs until discharge.**
Results—**Two patients died (1%) and 10 were unsuitable for analysis (5%). Of the remaining 189, 51 (27%) had atrial fibrillation (AF) lasting > 1 hour at a mean of 2 (0·5 to 7) days after CABG. Of the variables examined, only SAPWD (AF group 148 (SD 12), *v* 142 (14) ms, P = 0·008) and male sex (AF group 96%, *v* 78%, P < 0·01) were significantly different. A prospectively defined SAPWD of > 141 ms predicted atrial fibrillation with positive and negative predictive accuracies of 34% and 83%. Logistic regression analysis identified both male sex and SAPWD as significant independent predictors of postoperative atrial fibrillation.**
Conclusions—**Signal averaged P wave duration was a better predictor of atrial fibrillation after coronary bypass grafting than standard electrocardiographic or echocardiographic criteria. The predictive value of this test is such that it is likely to be useful in the design of prospective trials of prophylactic antiarrhythmic treatment but is of limited use using current techniques in the clinical management of individual patients.**

(*Heart* 1997;77:417–422)

Keywords: coronary bypass grafting; atrial fibrillation; signal averaged electrocardiography

Although atrial fibrillation remains the most common postoperative arrhythmia that occurs after coronary artery bypass grafting (CABG), definite clinical predictors have not been identified.[1-3] The incidence of atrial fibrillation after CABG varies between 10% and 40%.[4] While this arrhythmia is rarely fatal, it can cause significant discomfort from palpitations, dyspnoea, and occasionally chest pain, it is associated with a thromboembolic risk, and it delays hospital discharge.

Evaluation of the characteristics of the surface P wave from the standard electrocardiogram has been found by Buxton and Josephson to be moderately predictive of postoperative atrial fibrillation.[5] Recently two groups have investigated signal averaged electrocardiography of the surface P wave as a predictor of atrial fibrillation after CABG.[6,7] In one of these investigations patients with valve surgery were included in the patient group studied,[6] and in the other only a small number of patients were examined.[7] The predictive value of the signal averaged P wave was moderate in both of these studies and it has been suggested that analysis of the standard electrocardiogram may be as good as analysis of the more technically difficult and time consuming signal averaged electrocardiogram performed in these investigations.[8]

The aim of the prospective investigation described here was to compare directly the predictive value of standard electrocardiography, left atrial dimension derived from M mode echocardiography, and P wave characteristics after P wave specific signal averaging for the development of atrial fibrillation after CABG in a large group of patients undergoing first elective CABG.

Methods

STUDY DESIGN

Two hundred and one patients were recruited over a six month period from those attending our institution for first elective isolated

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Accepted for publication 28 January 1997

CABG. Patient recruitment was limited by the availability of Holter monitoring recorders. No other selection criteria were applied. Patients with minor degrees of valve disease that did not require operative intervention were not excluded, nor were those with previous arrhythmia. All patients gave informed consent to the study, which was approved by the hospital ethics committee.

In the 24 hours before CABG, patients underwent standard 12-lead electrocardiography, echocardiography including colourflow examination, and P wave specific signal averaging. Demographic variables, the presence or absence of clinical signs of cardiac failure, the cardiothoracic ratio from the erect preoperative PA chest x ray, preoperative cardiac medication, previous myocardial infarction, and previous cardiac arrhythmia were also recorded. Postoperatively patients were monitored continuously by both telemetry and Holter monitoring for the first 48 hours after surgery. Thereafter they had daily electrocardiograms, with additional studies if symptoms were reported. Sustained atrial fibrillation was defined as atrial fibrillation that lasted at least one hour on Holter monitoring, or which was documented on two standard electrocardiograms taken one hour apart. At discharge the patient's cardiac rhythm was noted and their drugs recorded. Special attention was paid to β blocker withdrawal during the perioperative period.[4]

STANDARD ELECTROCARDIOGRAPHY

Standard electrocardiograms were performed using a Hewlett Packard Pagewriter machine with high pass and notch filters switched off. Analysis was performed on magnified leads I, II, III, and V1 as described by Buxton and Josephson[5] and Morris *et al*.[9] Lead II P wave duration was defined as the time from the earliest onset of P wave activity in lead II to the last P wave activity in this lead. Total P wave duration was the time from the earliest onset of P wave activity in any of leads I, II, or III to the last P wave activity in any of these leads. The isoelectric interval was the difference between lead II P wave duration and total P wave duration (fig 1). Lead V1 was used to measure the P terminal force in lead V1 (PTF_{V1}), defined as the duration of the terminal (negative) part of the P wave in lead V1 in seconds multiplied by its depth in millimetres (assuming normal calibration) (fig 2). If the terminal P wave was positive the duration and amplitude of the portion of the P wave after the notch usually seen towards the centre of the waveform was measured. All measurements were performed by two independent observers. Interobserver variability was 10 ms (7·8%) for lead II duration, 9 ms (6·6%) for total P wave duration, 5 ms (33%) for isoelectric interval, and 0·005 (33%) for PTF_{V1}.

ECHOCARDIOGRAPHY

All patients underwent standard M mode, cross sectional, and colourflow echocardiography (HP Sonos 1500 or Sonos 2000). Diastolic left atrial diameter was measured from the M mode echocardiogram at the level of the aortic root using on screen callipers.

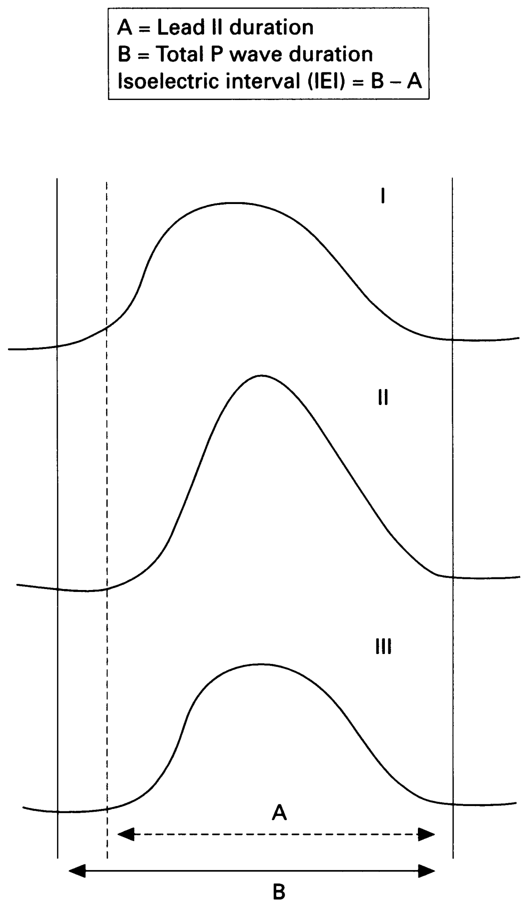

Figure 1 Measurement of P wave duration, total P wave duration, and isoelectric interval. Magnified standard leads I, II, and III are shown. P wave duration (A) is measured from standard lead II. Total P wave duration (B) is the interval between the earliest atrial activation seen in either leads I, II, or III to the latest deflection in any of these leads. The isoelectric interval is the difference between total P wave duration and P wave duration measured from lead II (that is, B–A). After Buxton et al.[5]

SIGNAL AVERAGED ELECTROCARDIOGRAPHY

Our signal averaging and P wave analysis methodology has been described previously.[10] Subjects were recorded supine and relaxed in

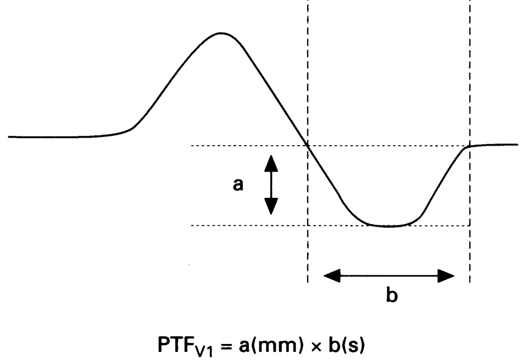

Figure 2 Determination of the P terminal force (PTF_{V1}). This measure of left atrial abnormality is defined as the maximum amplitude of the terminal negative portion of the P wave in lead V1 in mm multiplied by its duration in seconds. In cases where the terminal portion of the P wave is not negative it is defined as extending from the region where the P wave is notched to its end and the PTF_{V1} will have a positive sign.

Table 1 Clinical and demographic variables

	AF (n (%))*	SR (n (%))*	P
Age	62·8 (7·8)	60·6 (7·0)	NS
Male sex	49 (96)	108 (78)	< 0·01
Diagnosis	1: AVD	1: AVD	NS
	1: MVD	3: CCF	NS
Admission drugs			
β blocker	38 (75)	98 (71)	NS
Calcium antagonist	33 (65)	91 (66)	NS
Amiodarone	1 (2)	4 (3)	NS
Digoxin	0 (0)	4 (3)	NS
Previous arrhythmia			
PAF	3 (6)	5 (4)	NS
Palpitations	10 (20)	27 (20)	NS
VF	0 (0)	2 (1)	NS
Previous MI	32 (63)	72 (52)	NS
Heart failure			
JVP	1 (2)	7 (5)	NS
Crackles	1 (2)	4 (3)	NS
Oedema	3 (6)	19 (14)	NS
Discharge drugs			
β blocker	7 (13)	25 (18)	NS
Calcium antagonist	5 (10)	16 (12)	NS
Amiodarone	5 (10)	1 (1)	NS
Digoxin	30 (59)	11 (8)	< 0·001
β blocker withdrawal	32 (63)	78 (57)	NS

*All values are n (%) except for age which is presented as mean (SD) in years. MVD, minor mitral valve disease; AVD, minor aortic valve disease; CCF, congestive cardiac failure; PAF, previous paroxysmal atrial fibrillation; VF, ventricular fibrillation; MI, remote myocardial infarction; JVP, raised jugular venous pressure.

a quiet room. A modified orthogonal lead system was used. Between 100 and 200 beats were averaged to give a final filtered noise level of < 0·2 μV and an estimated low pass cutoff frequency of at least 70 Hz. Analogue signals were amplified between 4000 and 10 000 times, and bandpass filtered between 1 and 300 Hz. A fourth, trigger signal was derived from one of the orthogonal leads and used to align P waves during signal averaging. The latter signal was bandpass filtered between 20 and 50 Hz. Analogue data were then digitised at 1 kHz with 12 bit resolution.

Voltage threshold triggering using the R wave of the signal selected for the trigger channel was used to identify each electrocardiographic cycle. However, P waves were then aligned by template matching to an evenly spaced 15 point *P wave derived* template (that is, true P wave triggered averaging). An algorithm that automatically determined the most frequently occurring P wave morphology for each subject was used to select the averaging template. P waves with morphologies that failed to match this template accurately were rejected from the signal average. This technique averaged the most common P wave morphology for a particular individual to a close tolerance, ensuring high fidelity of the resultant averaged waveform.

After averaging, P wave signals were high pass filtered at 40 Hz using a 30 term finite impulse response filter and a vector magnitude plot was constructed. P wave limits were set automatically by an algorithm that identified the start of the P wave as the point at which the vector magnitude rose to more than three standard deviations above its baseline value and the P wave endpoint as the point at which the vector magnitude fell to within three standard deviations of the baseline value of the minimum PR segment magnitude. These limits were used to determine the P wave duration. Spatial velocity—the rate of change of the P wave voltage with respect to time—was calculated by digital differentiation between the limits defined above and mean, peak, and the ratio of peak to mean spatial velocity were measured. Spectral analysis comprised Fourier transformation of the entire unwindowed P wave after filtering at a high pass of 15 Hz.[10] From the resultant power density spectrum, the total energy contained in frequency bands from 20, 30, 40, 60, and 80 to 150 Hz was calculated.

Using the above signal averaging system we have found P wave duration to be a reproducible measurement[11] (coefficient of reproducibility 15 ms (11%)), although spatial velocity and P wave energy were less reproducible (for example, mean spatial velocity 1·44 mV/s (31%), P20 10·7 $\mu V^2/s$ (24·6%))

Table 2 Preoperative investigation results

	AF	SR	P
Chest x ray CTR	0·49 (0·05)	0·49 (0·05)	NS
Standard ECG			
Duration	128 (24)	127 (79)	NS
PTF_{V1}	−0·02 (0·03)	−0·01 (0·03)	NS
Total duration	139 (29)	136 (26)	NS
IEI	13·5 (17·11)	16·2 (18·5)	NS
Left atrial diameter	3·6 (0·4)	3·6 (0·4)	NS
Signal averaged ECG			
Noise	0·19 (0·08)	0·17 (0·08)	NS
Duration	148 (12)	142 (14)	0·008
Mean SV	3·29 (0·86)	3·26 (0·89)	NS
Peak SV	12·35 (4·1)	12·46 (4·4)	NS
Ratio peak/mean SV	3·74 (0·73)	3·78 (0·69)	NS
P20	34·1 (16·1)	34·4 (17·2)	NS
P30	19·8 (10·3)	20·9 (10·3)	NS
P40	8·56 (3·91)	9·76 (4·61)	NS
P60	2·80 (1·47)	2·72 (1·28)	NS
P80	1·20 (0·80)	1·17 (0·60)	NS

Values are mean (SD). CTR, cardiothoracic ratio; SV, spatial velocity, P20, P30, etc, energy in frequency bands from 20, 30, etc Hz to 150 Hz after spectral analysis; PTF_{V1}, P terminal force in lead V1 after Morris *et al*[9]; IEI, isoelectric interval after Buxton *et al*.[5]

STATISTICAL ANALYSIS

Categorical variables are presented as n (%). Continuous data are presented as mean (SD). Univariate comparisons between patients developing atrial fibrillation and those who did not were made by the χ^2 test for categoric data and the unpaired *t* test for continuous data. Multivariate analysis was by logistic regression.

Results

PATIENT CHARACTERISTICS

Of the 201 patients studied two (1%) died in the early postoperative period and 10 (5%) were excluded from analysis because of power-frequency contamination of their signal averaged P wave recordings leading to filtered noise levels of more than 0·3 μV. Of the remaining 189 patients 51 (27%) developed sustained atrial fibrillation at two (0·5 to 7) days after CABG. The age of the patients developing atrial fibrillation was 62·8 (1·1) years and of those remaining in sinus rhythm 60·6 (0·6) years (P = NS). There were significantly more males in the atrial fibrillation group than in the group who remained in sinus rhythm (49 (96%) *v* 108 (78%), P < 0·01). No other significant differences in clinical variables, prevalence of preoperative arrhythmia, admission drugs, discharge drugs, or β blocker withdrawal were noted apart from the expected excess of digoxin use at discharge in patients who had developed atrial fibrillation (30 (59%) *v* 11 (8%), P < 0·001) (table 1).

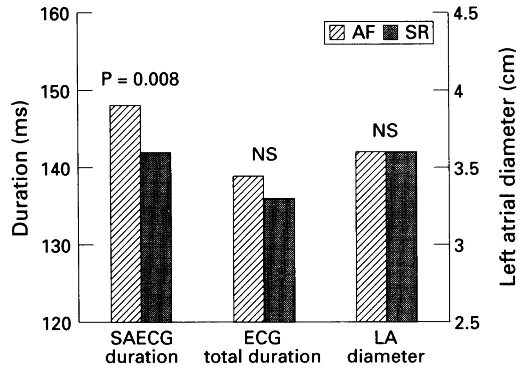

Figure 3 Difference in signal averaged P wave duration, total P wave duration measured from the standard electrocardiogram, and left atrial diameter in patients developing atrial fibrillation and those remaining in sinus rhythm after coronary bypass surgery. Mean values are presented. Only signal averaged P wave duration was significantly different between the groups.

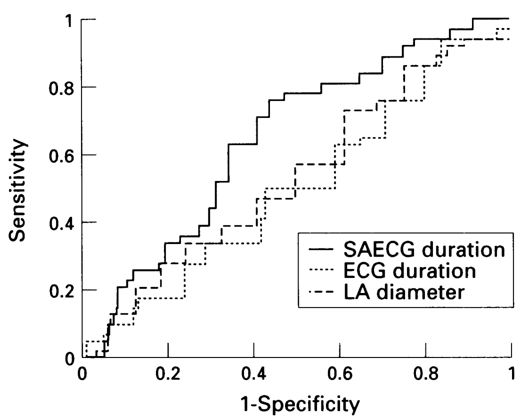

Figure 4 Receiver operator curves for signal averaged P wave duration, total P wave duration from the standard electrocardiogram, and left atrial diameter for prediction of atrial fibrillation after coronary bypass grafting. Sensitivity is plotted against 1 − specificity for a range of cutoff values for each variable. Deviation towards the top left of the graph by the curve representing signal averaged P wave duration implies increased discriminant ability over the other variables presented.

PREOPERATIVE ELECTROCARDIOGRAPHY AND ECHOCARDIOGRAPHY

No significant differences were observed between patients developing atrial fibrillation and those remaining in sinus rhythm in any variable derived from the standard electrocardiogram, or in left atrial diameter derived from the M mode echocardiogram. Filtered signal averaged P wave duration was significantly longer in patients who developed postoperative atrial fibrillation (148 (12) ms *v* 142 (14) ms, P = 0·008) (table 2) (fig 3).

Logistic regression analysis was performed on significant univariate predictors of postoperative atrial fibrillation. We have previously defined a filtered signal averaged P wave duration of more than 141 ms as predictive of paroxysmal atrial fibrillation.[12] Both male sex (odds ratio 2·4 (1·1 to 5·1), P = 0·02) and the prospectively defined signal averaged P wave duration cutoff (odds ratio 1·5 (1·0 to 2·0), P = 0·04) were identified as significant independent predictors of postoperative arrhythmia. A P wave duration of more than 141 ms predicted atrial fibrillation after CABG with a sensitivity of 73%, specificity of 48%, positive predictive accuracy of 34%, and negative predictive accuracy of 83% (fig 4).

Discussion

Our findings in a large homogeneous group of patients undergoing first elective CABG suggest that of the multiple preoperative clinical, electrocardiographic, and echocardiographic variables that we studied the only predictors of atrial fibrillation after CABG were filtered P wave duration, measured from the signal averaged electrocardiogram, and patient sex. After adjustment for the difference in sex between patients who developed atrial fibrillation after CABG and those who did not by logistic regression analysis, P wave duration remained a significant independent predictor. However, although signal averaged electrocardiography was a better predictor of postoperative atrial fibrillation than standard electrocardiography or echocardiography in these patients, the predictive ability of this technique was not high. The value of the technique for routine preoperative clinical use in individuals is therefore likely to be limited. No differences in measures of P wave energy or spatial velocity were noted in this group of patients, in contrast to the differences that we and others have reported between patients with paroxysmal atrial fibrillation and controls without arrhythmia.[12,13] This may be related to the poor reproducibility of these measures.[11]

Two previous groups have reported their experience with the use of preoperative signal averaged electrocardiography to predict atrial fibrillation after CABG.[6,7] Steinberg and colleagues analysed preoperative signal averaged P wave recordings in 130 patients, 21 (16%) of whom underwent valve surgery rather than isolated CABG.[6] In their series, signal averaged P wave duration was the only preoperative predictor of postoperative atrial fibrillation, with a sensitivity of 77%, specificity of 55%, and positive and negative predictive accuracies of 37% and 87%. Despite their inclusion of patients undergoing valve surgery in this series (which is likely to improve the apparent predictive ability of the signal averaged P wave for atrial fibrillation), these values are similar to those reported in our current analysis. Additionally, the cutoff value for P wave duration employed by Steinberg was similar, at 140 ms, to that reported in our current study, despite the use of a different P wave averaging system, suggesting that P wave duration may be similar between these two systems which both used non-recursive filtering of the signal averaged P wave before duration was measured. Klein *et al* also found that P wave duration was predictive of atrial fibrillation after CABG.[7] These investigators excluded patients who underwent valve surgery, but analysed only 54 subjects. In these patients, P wave duration predicted postoperative atrial fibrillation with a sensitivity of 69%, specificity of 79%, positive predictive accuracy of 65%, and negative predictive accuracy of 82%. These values, in a small number of subjects, are considerably better than those reported by ourselves and Steinberg, but may reflect the small number of patients studied.

Recently Frost *et al* have reported a comparison of P wave duration from the standard electrocardiogram and from the signal averaged electrocardiogram using a commercial system.[13] In contrast to our investigation and those of both Steinberg *et al* and Klein *et al* these investigators found that P wave duration measured from the standard electrocardiogram was slightly, but significantly, greater in patients who developed postoperative atrial fibrillation, whereas signal averaged P wave durations did not differ. These workers have previously published an analysis of the reproducibility of their signal averaging technique compared to analysis of the standard electrocardiogram, finding that the signal averaging technique they use (Aerotel HIPEC 200 system) was no better than analysis of the standard electrocardiogram.[14] The apparent disparity between our results, together with those of Steinberg *et al* and Klein *et al*, and those of Frost's group is unlikely to be related to differences in the patients studied, since we and Klein *et al* both studied a very similar patient group to Frost's. It seems more likely, therefore, that these differences are due to the use of different signal averaging methodology.

The results of our study and those of Steinberg *et al* suggest predictive values for the preoperative signal averaged P wave for postoperative atrial fibrillation similar to those previously reported by Buxton *et al* for analysis of the surface P wave from the standard electrocardiogram.[5] These investigators performed an analysis of P wave duration measured in standard leads I, II, and III. Total P wave duration, defined as the time from the earliest atrial activation to the last P wave signal in any of these three leads, was moderately predictive of postoperative atrial arrhythmia, as was the isoelectric interval (total P wave duration minus lead II P wave duration). A combination of prolonged total P wave duration and prolonged isoelectric interval predicted atrial fibrillation with a sensitivity of 66%, specificity of 70%, positive predictive accuracy of 48%, and negative predictive accuracy of 83%. The similarity of these results, using the standard electrocardiogram, to those achieved by signal averaged electrocardiography has led to the suggestion that the more complex and costly signal averaged electrocardiogram is no better for prediction of postoperative atrial arrhythmia than the simpler and cheaper standard test.[8] However, Buxton's series was analysed approximately 13 years before those reporting the results of signal averaged electrocardiography, and contained a greater proportion of patients who developed atrial flutter than either our sample or that of Steinberg. Direct comparisons of the two techniques from these data alone are therefore likely to be of limited value.

Both Steinberg *et al* and Klein *et al* measured P wave duration in lead II of the standard electrocardiogram, finding it to be inferior to signal averaged P wave duration for the prediction of atrial fibrillation after CABG. However, this result can easily be inferred from Buxton's original data if only lead II duration is measured. Frost measured total P wave duration, but not the isoelectric interval, finding it to be a better univariate predictor of postoperative atrial fibrillation than the signal averaged P wave duration because of an apparent correlation with patient age. Thus P wave duration from the standard electrocardiogram was not an independent predictor of postoperative atrial fibrillation when a multivariate model including patient age was employed. In our present investigation we report a comparison of variables derived from the signal averaged P wave with those derived according to the methods described by Buxton, thereby affording a direct comparison in the same patient group of the relative clinical value of the two techniques. Our results show that the signal averaged P wave is a better predictor of postoperative atrial fibrillation than analysis of the surface P wave from the standard electrocardiogram. Moreover, our data also suggest that signal averaged P wave duration is independently predictive of atrial fibrillation after CABG, although its predictive power remains only modest.

It is perhaps surprising that preoperative signal averaged electrocardiography has any predictive ability for postoperative atrial fibrillation, since very few of the patients in our series had a history of past atrial arrhythmia. Previous studies have examined the signal averaged P wave in patients with documented atrial fibrillation, finding the P wave to be longer and to contain greater energy than in controls.[15-17] Increased P wave duration in patients awaiting CABG therefore seems to detect a subclinical propensity to atrial fibrillation that becomes apparent after additional trigger factors associated with the operation. As such the preoperative signal averaged P wave may identify a subgroup of patients who could be targeted in controlled trials of prophylactic antiarrhythmic treatments. Further study of the *postoperative* signal averaged P wave may be rewarding.

CONCLUSIONS

Prospective analysis of standard electrocardiography, left atrial diameter from M mode echocardiography, and the signal averaged P wave in patients about to undergo elective first CABG showed that signal averaged P wave duration was the best predictor of postoperative atrial fibrillation. The diagnostic accuracy of this test might be sufficient to identify a group of patients at increased risk of postoperative atrial fibrillation, but using current techniques it is of limited clinical value in individual patients.

1 Fuller JA, Adams CG, Buxton B. Atrial fibrillation after coronary bypass grafting. *J Thorac Cardiovasc Surg* 1989;97:821–5.
2 Leitch JW, Thompson D, Baird DK, Harris PJ. The importance of age as a predictor of atrial fibrillation and flutter after coronary bypass grafting. *J Thorac Cardiovasc Surg* 1990;**100**:338–42.

3 Yousif H, Davies G, Oakley CM. Perioperative supraventricular arrhythmias in coronary bypass surgery. *Int J Cardiol* 1990;**26**:313–8.
4 Frost L, Molgaard H, Christiansen E, Hjortholm K, Paulsen P, Thompson P. Atrial fibrillation and flutter after coronary artery bypass surgery: epidemiology, risk factors and preventive trials. *Int J Cardiol* 1992;**36**:253–61.
5 Buxton AE, Josephson ME. The role of P wave duration as a predictor of postoperative atrial arrhythmias. *Chest* 1981;**80**:68–73.
6 Steinberg JS, Zelenkofske S, Wong S-C, Gelernt MN, Sciacca R, Menchavez E. The value of the P-wave signal-averaged electrocardiogram for predicting atrial fibrillation after cardiac surgery. *Circulation* 1993;**88**:2618–22.
7 Klein M, Evans SJ, Blumberg S, Cataldo L, Bodeheimer MM. Use of P-wave-triggered, P-wave-signal-averaged electrocardiogram to predict atrial fibrillation after coronary bypass surgery. *Am Heart J* 1995;**129**:895–901.
8 Seifert M, Josephson ME. P-wave signal averaging. High tech or an expensive alternative to the standard ECG? *Circulation* 1993;**88**:2980–2.
9 Morris JJ, Estes EH, Whalen RE, Thompson HK, McIntosh HD. P-wave analysis in valvular heart disease. *Circulation* 1964;**29**:242–52.
10 Stafford PJ, Denbigh PN, Vincent R. Frequency analysis of the P wave: comparative techniques. *PACE* 1995;**18**:261–70.
11 Stafford PJ, Cooper J, Fothergill J, Schlindwein F, deBono DP, Garratt CJ. Reproducibility of the signal averaged P wave. *Heart* 1997;**77**:412–16.
12 Stafford PJ, Robinson D, Vincent R. Optimal analysis of the signal averaged P wave in patients with paroxysmal atrial fibrillation. *Br Heart J* 1995;**74**:413–8.
13 Frost L, Lund H, Pilegaard H, Christiansen EH. Re-evaluation of the role of P-wave duration and morphology as predictors of atrial fibrillation and flutter after coronary artery bypass surgery. *Eur Heart J* 1996;**17**:1065–71.
14 Christiansen EH, Frost L, Pilegaard H, Toftegaard-Nielsen T, Pedersen AK. Within- and between-patient variation of the signal averaged P wave in coronary artery disease. *PACE* 1996;**19**:72–81.
15 Yamada T, Fukunami M, Ohmori M, Kumagai K, Sakai A, Kondoh N, *et al.* Characteristics of frequency content of atrial signal-averaged electrocardiograms during sinus rhythm in patients with paroxysmal atrial fibrillation. *J Am Coll Cardiol* 1992;**19**:559–63.
16 Opolski G, Stanislawska J, Slomka K, Kraska T. Value of the atrial signal-averaged electrocardiogram in identifying patients with paroxysmal atrial fibrillation. *Int J Cardiol* 1991;**30**:315–9.
17 Guidera SA, Steinberg JS. The signal averaged P wave duration: a rapid and noninvasive marker of risk of atrial fibrillation. *J Am Coll Cardiol* 1993;**21**:1645–51.